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THE HOLDOUT GAME: AN EXPERIMENTAL STUDY OF AN INFINITELY REPEATED GAME WITH TWO-SIDED INCOMPLETE INFORMATION

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ABSTRACT

We investigate experimentally a two-person infinitely repeated game of incomplete information. In the stage game, each player chooses to give in or hold out. Players have privately known costs of giving in and each player receives a fixed benefit whenever at least one player gives in. High cost players have a dominant strategy in the stage game to hold out, and the low cost players' best response depends on what the opponent does. Equilibrium play to the infinitely repeated game conveys information about the players type.

We investigate two questions: whether there is any evidence that subject behavior approximates *belief stationary* equilibria, and whether there is evidence that subjects will converge to an equilibrium of the correct state. We conclude that subjects do not adopt symmetric belief stationary strategies for the holdout game. However, we cannot reject the hypotheses that subjects converge towards eventually playing an equilibrium of the correct state (even though they do not always learn the correct state). Behavior of experienced subjects is closer to the predictions of symmetric belief-stationary equilibrium.

The Holdout Game: An Experimental Study of an Infinitely Repeated Game with Two-Sided Incomplete Information[1]

1 INTRODUCTION

This paper investigates a two-person infinitely repeated game of incomplete information, in which each player has private information on his/her type before the first game is played, and this is followed by a infinite sequence of identical simultaneous-move stage games. Players observe their own payoff and the other player's move after each stage game has been played. Payoffs in the game are given by the discounted sum of payoffs in all the stage games.

The information structure is that each player knows his/her own type, but only the distribution from which the other player's type was drawn. The types of the two players are drawn independently, and each player's payoff function in the stage game is determined solely by his/her own type. Thus it is what is sometimes referred to as an *independent private values* situation.

Games of this sort fall in a class of games that have been studied in a recent collection of papers by Kalai and Lehrer (1991), Jordan (1991a, 1991b, 1992), McKelvey and Palfrey (1992). Jordan (1991b) establishes the existence of a Bayesian Nash equilibrium of the infinitely repeated game and Kalai and Lehrer (1991) and Jordan (1991b) prove that in every Bayesian Nash equilibrium, eventually the sequence of play along the equilibrium path will be empirically indistinguishable from play that could have arisen at some Nash equilibrium of the infinitely repeated game in which the actual draws of the two players were common knowledge. In other words, enough information is leaked in the early rounds of play so that play eventually mimics an equilibrium as if the players' types have been perfectly revealed. The "as if" caveat is relevant; the theorems do not imply that players' beliefs about each other's type converges to complete information (i.e. to a degenerate posterior at the true type).

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As interesting as these theorems are, other results from the folk theorem literature suggest that they place few restrictions on the possible patterns of equilibrium play. McKelvey and Palfrey (1992) propose a stationarity requirement which imposes very strong restrictions on the equilibrium play. This is called ***belief-stationarity*** and requires that the behavioral strategies at a given stage can depend on history only to the extent that different histories lead to different common knowledge beliefs about player types. In other words, if players have common knowledge beliefs π at stage t and π at stage t', then each player must be mixing over his or her actions with the same probability distribution at stage t' as at stage t. In that paper, they also show that even with such a stationarity restriction, equilibrium play along some paths may be very complicated, exhibiting a rich nonlinear dynamic in which the trajectory of beliefs along such a path is chaotic.

Nonetheless, in some games, belief stationarity leads to the selection of a unique subgame perfect equilibrium. Thus, the motivation for this refinement is in much the same spirit as the restrictions on equilibrium imposed in much of the bargaining literature with complete information, following Rubinstein (1982). There one also finds that stationarity (of a different sort) selects a unique equilibrium among an otherwise indeterminate set of possible equilibria.

This raises some obvious questions: as an empirical matter, how does play proceed in these games? Is there evidence that players are playing some Bayesian Nash equilibrium? Does the belief stationary equilibrium provide an accurate prediction for play? Does the sequence of play eventually converge to "complete information play"? What empirical regularities or anomalies can be identified?

We investigate these questions experimentally in the context of a simple bargaining game, that we call ***the holdout game***, which is related to a simultaneous-move version of the bargaining game studied by Chatterjee and Samuelson (1987). At each point in time, a player may either hold out (H) or give in (G). Each player has two types. One of the types is a tough player, who has a dominant strategy in the stage game of holding out. The other type's best response in the stage game depends on the probability that his/her opponent will give in. If that probability is sufficiently high, then he/she should give in; if it is sufficiently low, he/she should hold out. One can think of the game as a simple caricature of a bargaining game, where agreement hinges on at least one of the sides making a concession on a particular feature of the contract being negotiated. The types then index some combination of the costs to making the concession and the value of the other terms of the contract. Section 2 solves for a symmetric belief-stationary equilibrium of the game. Section 3 describes the experimental procedures and the specific parameters of the games that were conducted in the laboratory. Section 4 presents the results of the experiment.

2 THE HOLDOUT GAME

The holdout game is a two person infinitely repeated game of incomplete information whose stage game is given in the following matrix:

	G		H	
G	$1-c_1$	$1-c_2$	$1-c_1$	1
H	1	$1-c_2$	0	0

In each round, either player can either give in (G) or hold out (H). If neither player gives in, then both players receive a payoff of 0. The basic value of agreement is equal to 1, and both players receive this if at least one player gives in. The cost to player i of giving in equals c_i.

In the analysis that follows, we make the following assumptions. Each player has two possible types (values of c_i), c_L and c_H. We assume $c_L < 1 < c_H$. To save on notation we write $c = c_L$. Thus in a one-shot game, a c_H-type (or "high cost" type) has a dominant strategy of holding out, and a c-type (or "low cost" type) does not have a dominant strategy. Types are independently drawn with the probability that $c_i = c$ equal to q_1 for player 1 and q_2 for player 2, which is common knowledge.

One Shot Bayesian Equilibrium

Before analyzing the infinitely repeated version of the holdout game, we characterize the solution to the one shot game.

There are three classes of equilibria to the one shot game, depending on the relative values of c, and $q = (q_1, q_2)$. In one kind of equilibrium, one player adopts a separating strategy (i.e. choose H if $c_i = c_H$, and G if $c_i = c$) and the other player always holds out, regardless of type. These equilibria exist if q_i is sufficiently large for at least one of the players. A second kind of equilibrium arises in which both players adopt separating strategies. These arise if q_i is low for both players.

The third kind of equilibrium is one in which both players adopt semi-pooling strategies (i.e. player i chooses H if $c_i = c_H$ and choose G with probability $p_i > 0$ if $c_i = c$). Routine calculation shows that the equilibrium p_i depends on q_i and c in the following way:

$$p_i(q) = (1-c)/q_i$$

In this equilibrium, both players obtain an expected utility of $1-c$. This feature of the equilibrium will simplify later calculations. This kind of equilibrium only arises if $q_i > 1-c$ for both players. Except for knife edge cases, there are no other kinds of equilibrium.

The Infinitely Repeated Game

In the infinitely repeated version of the holdout game, we assume both players discount future payoffs using the same discount factor, δ, and we solve below for a symmetric belief-stationary perfect Bayesian equilibrium. We also conjecture that the equilibrium is unique if $c + \delta > 1$.

A belief-stationary strategy profile is a collection of four functions, $p_{H1}(q_1, q_2)$, $p_1(q_1, q_2)$, $p_{H2}(q_1, q_2)$ and $p_2(q_1, q_2)$, denoting, for each possible type of each player, the probability of giving in as a function of the currently held beliefs of both players about the type of the other player. Thus, q_1 denotes the current belief held by player 2 that player 1 is a low type, and q_2 denotes the current belief held by player 1 that player 2 is a low type. Symmetry requires that $p_{H2}(q, q') = p_{H1}(q', q)$ and $p_2(q, q') = p_1(q', q)$ for all (q', q) in the unit square. To reduce notation, we drop the player subscripts, and simply look at the strategy of player 1, denoted $p_H(q_1, q_2)$ and $p(q_1, q_2)$.

Characterization of a symmetric belief stationary equilibrium is done by first solving the game at the boundary of the unit square of beliefs (i. e., for one sided incomplete information,) which then pins down the equilibrium mixing probabilities for interior values of q (i.e. before either player's type has been revealed). This latter task is nontrivial, but in our case, it is simplified since there is an equilibrium in which high cost types always hold out. We conjecture that p_H must identically equal 0 for all beliefs in any belief-stationary equilibrium. The reason is that belief-stationarity rules out the kind of history-dependent strategies used in folk-theorem constructions. Without such punishment schemes, it would not seem to be possible to provide intertemporal threats and incentives to induce high cost types to violate their one-shot dominant strategies. While this is not formally proved, we nonetheless restrict attention in the remainder of the paper to the equilibrium with $p_H = 0$.

We proceed in two steps. First we show that if beliefs begin on the diagonal ($q_1 = q_2$), the unique equilibrium path implies to a trajectory of beliefs that remain on the diagonal until, after some point, they jump to the boundary. We then characterize the symmetric belief stationary equilibrium on the diagonal and on the boundary of beliefs space. A solution off the diagonal is given in McKelvey and Palfrey (1993).

For any $q = (q_1, q_2)$ we define $V(q{:}\sigma)$ to equal the value to player 1 of the continuation game under the strategy profile σ. We suppress the dependence on σ and simply write this as $V(q)$. Similarly, we define $V^G(q)$ (or $V^H(q)$) to be the value to player 1 in the continuation game if G (or H, respectively) is chosen in the current period. We denote V_{GG} and the future continuation value (starting next period) to player 1 if both players choose G in the current period; V_{GH}, V_{GH} and V_{HG} are defined analogously. Finally we assume, throughout:

ASSUMPTION 1: $c + \delta > 1$

We first prove that if beliefs are on the diagonal, then in any symmetric belief stationary equilibrium, the beliefs in the continuation game of the next period are either on the diagonal or on the boundary of the belief space. At the boundary, at least one player's type is common knowledge. Therefore, once beliefs reach a boundary, they stay on the boundary forever.

PROPOSITION 1 If $q = (q_1, q_2)$ satisfies $q_1 = q_2 = q$, then along any symmetric belief-stationary equilibrium path, the updated beliefs at the beginning of the next period, $\widehat{q} = (\widehat{q}_1, \widehat{q}_2)$, must satisfy either, $\widehat{q}_1 = \widehat{q}_2 < q$ or $\widehat{q}_1 = 1$ or $\widehat{q}_2 = 1$.

Proof: We first show that $q_1 = q_2 = q$ implies $p(q) > 0$. If $p(q) = 0$, then $\widehat{q} = q$ since both types hold out. But this implies $V(q) = 0$, by stationary and symmetry. But player 1 can guarantee $\frac{1-c}{1-\delta} > 0$ by giving in forever, a contradiction. Since $p(q) \geq 0$, there are four possible histories: (GG, GH, HG, HH). The updated beliefs are, respectively:

$$(1,1), (1, \frac{(1-p)q}{1-pq}), (\frac{(1-p)q}{1-pq}, 1), (\frac{(1-p)q}{1-pq}, \frac{1-p)q}{1-pq}).$$

PROPOSITION 2 If $q_1 = 1$ then $V(q) = \frac{1-c}{1-\delta}$.

Proof: If $q_2 = 1$ too, then the unique symmetric belief stationary equilibrium is infinite repetition of the unique one-shot symmetric Nash equilibrium, where $p = 1 - c$. This yields a value of $\frac{1-c}{1-\delta}$. The remainder of the proof consists of showing that when $q_1 = 1$ and $q_2 < 1$, the unique equilibrium has $p(q) = 1$. This implies the result directly. To prove this, first observe that for low values of q_2 ($q_2 < 1 - c$) the revealed player (player 1) will always choose G because

$$V^H \leq q_2(\frac{1}{1-\delta}) < \frac{1-c}{1-\delta} = V^G.$$

(Recall that $\frac{1}{1-\delta}$ is the highest feasible continuation payoff.) Accordingly, player 2 will hold out, so $\widehat{q}_2 = q_2$.

Next, consider $q_2 \geq 1 - c$ and observe that for the revealed player to have $p_1 < 1$, we must have $p_2 q_2 \geq 1 - c$, since the value of continuation to player 1 does not depend on player 1's move (by belief stationarity). This requires $p_2 \geq \frac{1-c}{q_2}$. Therefore, following H by player 2, Bayes rule implies:

$$\widehat{q}_2 < \frac{q_2 + c - 1}{c}.$$

So, for values of q_2 between $1 - c$ and $1 - c^2$, this implies $\widehat{q}_2 < 1 - c$. Therefore, the continuation game following H by player 2 will have player 1 choosing G forever and player 2 choosing H forever. This gives

$$V_2^H(q) = p_1 + \frac{\delta}{1-\delta},$$

while

$$V_2^G(q) = \frac{1-c}{1-\delta}.$$

So $V_2^G(q) \geq V_2^H(q)$ requires $c + \delta \leq 1$, a contradiction. Therefore, $V_2(q) = \frac{1}{1-\delta}$ for $q_1 = 1, q_2 < 1 - c^2$.

The argument is now completed by induction. Suppose that the equilibrium must always satisfy $p_1 = 1, p_2 = 0$ for q_1 and $q_2 < 1 - c^{n-1}$. Then it must also be true for $q_2 < 1 - c^n$.

PROPOSITION 3 For all $\boldsymbol{q} = (q_1, q_2)$, such that $q_1 > 0$, $p(\boldsymbol{q}) > 0 \rightarrow V(\boldsymbol{q}) = \frac{1-c}{1-\delta}$.

Proof: If $p(\boldsymbol{q}) > 0$, then $V^G(\boldsymbol{q}) = V(\boldsymbol{q})$. But $V^G(\boldsymbol{q}) = \frac{1-c}{1-\delta}$ since $\widehat{q}_1 = 1$ if player 1 chooses G, and $V(1, \cdot) = \frac{1-c}{1-\delta}$.

PROPOSITION 4 If $\boldsymbol{q} = (q_1, q_2)$, with $q_1 = q_2 = q > P = \frac{(1-c)(1-\delta)}{1-\delta(1-c)}$, then $p(\boldsymbol{q}) = \frac{P}{q}$.

Proof: It is easily verified that $p(\boldsymbol{q}) < 1$ in the region of $\boldsymbol{q}$. By proof of proposition 1, $p(\boldsymbol{q}) > 0$. Therefore we must have $V^G(\boldsymbol{q}) = V^H(\boldsymbol{q}) = \frac{1-c}{1-\delta}$. Thus,

$$V^G(q) = \frac{1-c}{1-\delta} = V^H(q) = pq\frac{1}{1-\delta} + (1-pq)\delta\frac{1-c}{1-\delta} \Rightarrow p = \frac{P}{q}.$$

PROPOSITION 5 If $q = (q_1, q_2)$, satisfies $q_1 = q_2 = q \leq P$, then $p(q) = 1$.

Proof: From above, there is no mixed strategy equilibrium when $p > q$. From Proposition 1, $p(\boldsymbol{q}) > 0$. Thus, $p(\boldsymbol{q}) = 1$ is the only possibility. Routine calculations verify this.

3 EXPERIMENTAL DESIGN AND PROCEDURES

We conducted 6 laboratory sessions using a total of 80 subjects who were undergraduate students at California Institute of Technology and Pasadena Community College. The sessions were carried out on a system of networked computers at the Caltech Laboratory for Experimental Economics and Political Science. Subjects were seated at terminals that were separated by partitions. Communication between subjects was prohibited.

At the beginning of each session, the subjects were randomly divided into equal-sized sets of red players (the row players) and blue players (the column players). Instructions were read aloud to the subjects and the rules and information structure of the games they were about to play were publicly announced and explained.

The subjects then played a sequence of between 12 and 15 (depending on how long each game lasted) "stochastic horizon" repeated games, called "matches". In each match, each red subject was matched with a blue subject, each player was randomly assigned a cost-type, and each pair repeatedly played the game until the termination rule was satisfied. A stochastic horizon was induced by using a random stopping rule, which was implemented by publicly rolling a 10-sided die after each play of the game. The "infinite game" terminated if a 1 was rolled, in order to induce a discount factor of $\delta = .9$.

After a match, the draw of the opponent's type was revealed to each player. Except after the last match, subjects were then anonymously rematched with a different player of the other color, and everyone reassigned a new type. They were never told the identity of the players they were matched with, nor were they told the sequence in which their opponents were assigned (except that it was "a new opponent" in the next match). Subjects were informed that their type and the type (and identity) of their opponent remained the same in every period of any given match. The complete instructions are in Appendix A.

At the conclusion of the experiment, subjects were paid in lottery tickets, following a standard procedure for inducing risk neutral preferences over risky outcomes. We felt that such a control was important to rule out risk aversion as a possible explanation for any deviations from the theoretical predictions that might be observed.

The payoffs used in the experiment consisted of the following four payoff matrices. The payoff matrices corresponding to the four possible pairs of cost-types are labeled 1-4. At the beginning of each match, one of the four states (matrices) was randomly selected. The row player (Red) was told which row the selected matrix was in, and the column player was told which column the selected matrix was in. For example, if matrix 2 was selected, Red was told it was either 1 or 2, and Blue was told it was either 2 or 4. The payoffs were presented arbitrarily, with no reference to "cost-type", "hold-out", or "give in", etc. Strategies were labeled "A" and "B", where A corresponds to Give In and B corresponds to Hold Out.

	1				2	
	A	B			A	B
A	4,4	4,6		A	4,1	4,5
B	6,4	2,2		B	6,1	2,4

	3				4	
	A	B			A	B
A	1,4	1,6		A	1,1	1,5
B	5,4	4,2		B	5,1	4,4

Payoff Tables used in the Experiments

The payoffs were chosen to produce a game equivalent to the holdout game with parameters $c = .5$ and $c_H = 4$, with the probability of a low cost type equal to .75. The top (left) two payoff tables correspond to a low cost type for Red (Blue), and the bottom (right) two matrices correspond to a high cost type for Red (Blue). The payoff tables differ cosmetically from the game that is studied in the previous section, but the game is equivalent to the game analyzed in that part of the paper. This is true because the utility function of each type is a positive linear transformation[2] of the utility for the corresponding type in the matrix of Section 2.

The information structure in all matches except the first four followed exactly the information structure described in the theoretical model of section 2. The first four matches were conducted as repeated games of complete information in order for the subjects to gain some experience with the screen display and keyboard, the record keeping tasks, and the way lottery tickets converted into money. This also afforded them an opportunity to become familiar with some of the most basic strategic elements of each of the four component games, corresponding to the four possible type profiles, $(c, c), (c, c_H), (c_H, c)$, and (c_H, c_H). These four matches were conducted in that exact sequence. A discount factor of $\delta = .75$ was induced in these complete information

[2]To obtain the payoff function of Section 2, subtract 2 units from the payoffs of the low types and then divide by four, and subtract 4 units from the payoffs of the high types.

games to reduce the amount of time they took. In these matches, each subject was told the opponent's type before the first period of the match by telling them exactly which one of the four payoff matrices was being used, and this was made common knowledge.

After approximately two hours, the experimental session was ended following the termination of a match. Subjects were then paid their earnings privately in cash, one at a time, in an adjoining room.

4 DATA ANALYSIS

The data analysis addresses three questions. First, how well does the symmetric belief stationary equilibrium account for the data in our experiment? Second, is there evidence that subjects eventually play an equilibrium strategy for the true state? Third, does behavior change across matches, as subjects become more experienced?

Our data consisted of a total of 239 matches of varying length, which yielded a total of 370 Low type subjects and 108 High type subjects. The matches were distributed among the four information states as in Table 1. The actual and expected distribution of match lengths are given in Figure 1 and Table 2.

		Player 2: Low	Player 2: High	
Player 1	Low	141	48	189
	High	40	10	50
		181	58	239

Table 1
Frequency of information states in experimental matches

T	$f(T)$
1	28
2	10
3	20
4	12
6	11
7	14
8	24
9	34
10	5
11	19
12	6
13	14
15	12
22	11
28	8
30	5
35	6
Total	239

Table 2

Frequency Distribution of Match Lengths

Belief stationarity

The first question is addressed by comparing the data to the predictions of propositions 1-4 in Section 2 of the paper. We separate out the predictions for the high and low types.

The prediction for the high types is that they should never give in. Table 3 displays the data relevant to this hypothesis. (See also Figure 2.) On the first move 9% ($n = 108$) of the high types choose to give in. This drops to an average of about 2-3% after the first round. The average probability of giving in, across all rounds, is about 3% ($n = 1165$). The data in Table 1 are aggregated across all incomplete information matches.

Round	%	n
1	0.0926	108
2-5	0.0242	330
6-10	0.0277	325
11-20	0.0251	239
21-30	0.0362	138
31-36	0.0000	25
Total	0.0326	1165

Table 3
Proportion of High types giving in
by round

The prediction for the low types is more complicated. On the first move, the low types should give in with probability .121. The actual frequency that the low types give in on the first move is 44% (n=370).

On the subsequent moves, the prediction for the low types depends on the history. As long as neither subject has given in, the low types should update their beliefs to a continually lower estimate that the opponent is a low type, and the probability that they give in should gradually increase, from .121 in the first move to about .15 in move 5. The predicted and actual proportion of low types that give in when neither subject has yet given in is given in Table 4. (See also Figure 3.) It is evident that the proportion that actually give in is significantly higher than the predicted proportion.

Round	p^*	p	n
1	.121	.441	370
2	.125	.454	119
3	.130	.435	46
4	.136	.353	17
5	.143	.182	11
6	.152	.444	9
7	.163	.667	3
8	.177	.000	1
Total	.124	.436	576

Table 4
Predicted (p^*) and actual (p) proportion of Low types giving in when neither subject has revealed

Given that one or both players have revealed themselves to be a low type (by choosing to give in) the equilibrium strategy for the low type is as follows: If both subjects simultaneously revealed themselves to be low, then both players should subsequently choose to give in with probability .5 in each round. If only the opponent has given in, then the player should give in with probability 0. If the player in question has given in, but the opponent has not, then the player should give in with probability 1. Table 5 shows the data for the Low types in the case when at least one subject has revealed. (See also Figure 3.) In the early rounds, there are occasional attempts by the subject who has revealed to refrain from continuing to give in. Also, about ten percent of the time, the subject who has not revealed will reveal even after the other subject has already revealed. After about the fifth round, the figure shows that at least at a highly aggregated level, the behavior is fairly consistent with the equilibrium predictions.

In addition to giving round by round data, Table 4 also gives the frequency of giving in on the first move after at least one subject has revealed. This is in the row labeled "First Revelation." Here also, ten percent of the time, the subject who has not yet revealed reveals after the opponent has revealed.

		Player that has revealed					
		Both	n	Self	n	Other	n
Predicted		.500		1.00		0.00	
	2	.327	55	.789	90	.103	68
R	3	.605	81	.877	114	.132	76
O	4	.465	99	.848	105	.095	63
U	5	.533	105	.917	96	.122	49
N	6-10	.561	472	.913	381	.012	163
D	11-20	.541	290	.955	242	.000	95
	21-35	.462	121	.955	134	.029	34
	Total	.529	1223	.908	1162	.058	548
First Revelation		.500	80	.826	149	.100	90

Table 5
Proportion of Low Types Giving in by whether subject and
Opponent have Revealed (R) or Not (N)

Although Table 5 shows that in the case where both subjects have revealed their type, that the subjects give in approximately 50% of the time (as predicted), this masks what is really going on in the data. If we look at individual level data, we find that in most of these cases, one of the subjects is giving in every round, while the opponent is holding out every round. Thus, at the aggregate level, 50% of the subjects in this category are giving in, but in fact all pairs are playing a pure strategy equilibrium. Table 6 illustrates this phenomenon. (See also Figure 4.) This table displays the probability of giving in as a function of the previous period move. We see that if both subjects have given in, or both subjects have held out, then there is about a 50% chance of giving, or holding out on the next move. Thus these two categories tend to empty out, and get smaller over time. On the other hand, once one subject gives in, and the other holds out, that pattern persists with a probability of at least .9 (by move 5) into the next move. Thus eventually, each pair settles into a pure strategy equilibrium where one player holds out, and the other mixes. We do not see mixing or alternation schemes. This pure strategy equilibrium occurs even when both subjects have revealed their type.

Round	GG	n	GH	n	HG	n	HH	n
2	.327	55	.789	90	.103	68	.454	119
3	.710	38	.887	106	.129	70	.476	103
4	.546	44	.838	117	.103	78	.378	45
5	.478	23	.893	112	.119	67	.559	59
6-10	.566	122	.913	496	.100	279	.538	132
11-20	.539	26	.962	366	.033	210	.600	25
21-35	.333	3	.945	182	.000	82	.545	22
Total	.527	311	.912	1469	.079	854	.497	505

Table 6

Probability of Low type giving in
as a function of move of subject and opponent in previous round

Our second question concerns whether there is any evidence for the theorems of Kalai and Lehrer and Jordan (KL-J). Do subjects eventually play an equilibrium for the correct state? We should emphasize that there is no way that we could present evidence that would refute this assertion. First, the theorems say nothing about how long it should take for convergence. Second, once we drop the assumption of belief stationarity, folk theorems may apply, and we must consider the possibility that nearly any pattern of play that we see in the first K periods might be part of an equilibrium to the infinitely repeated game that could be enforced by sufficiently severe punishments off the equilibrium path. Thus, the most we could hope to do is present any obvious evidence supporting the KL-J hypothesis, if such evidence exists.

A first question relevant to the KL-J hypothesis is whether subjects were able to figure out the correct state. In our experiments, after each match was over, we asked subjects to guess the true state before it was revealed to them. We did not pay subjects anything to reveal this information to us, since we did not want to contaminate their incentives for choosing optimal strategies. Nevertheless, they had no obvious reason to intentionally misreport this information. We summarize it in Table 7. Table 7 shows that subjects were only able to guess the state correctly about 68% of the time. Players who were high types did better than low types, and all subjects did somewhat better when their opponent was a low type than when their opponent was a high type. This is what one would expect at the predicted equilibrium. There does not seem to be any increase in the success rate as the length of the match increases. In fact, if anything, the accuracy of the prediction goes down as the length of the match increases, indicating that the early periods reveal most, if not all of the information that is revealed.

	Player Type				
	High		Low		
	Opponent		Opponent		
	H	L	H	L	Total
$T > 0$	.737 (19)	.786 (84)	.560 (84)	.685 (257)	.682 (444)
$T > 5$	.714 (14)	.814 (59)	.576 (59)	.664 (176)	.679 (308)
$T > 10$	.600 (10)	.769 (26)	.539 (26)	.667 (84)	.657 (146)

Table 7

Percent correct guess of state
by player type, opponent type, and length (T) of match

Of course, the KL-J hypothesis does not require that subjects learn the correct state, only that they play an equilibrium of the correct state. To address this question, we will select some salient equilibria for each state, and find out how frequently in our experiments, the subjects eventually select one of the equilibria of the correct state.

Once we drop the condition of belief stationarity, a strategy is a function which determines for each possible history, h, a probability $p(h) = (p_1(h), p_2(h))$ that each player will give in. Consider the following equilibria for each state

Both High	$p(h) = (0,0) = p_{HH}$ for all h
One High, two Low	$p(h) = (0,1) = p_{HL}$ for all h
One Low, two High	$p(h) = (1,0) = p_{LH}$ for all h
Both Low	$p(h) = (1,0) = p_{LL1}$ for all h, or $p(h) = (0,1) = p_{LL2}$ for all h

We cannot, of course observe behavior for histories that do not occur in the data. Instead, we simply check whether the data in our experiments converges to the equilibrium play that is predicted by the above strategies. For each match, and each round t, and each player, i, we compute the cumulative average $\overline{p}_i(t)$ up to time t that player i has given in. Write $\overline{p}(t) = (\overline{p}_1(t), \overline{p}_2(t))$. Convergence to equilibrium entails that for each true state s, $lim_t\ \overline{p}(t) \rightarrow p_s^*$, where p_s^* is one of the selected equilibria for the true state. Figures 1-4 show the results of these calculations, with one figure for each true state. These figures show the time path of the difference $\overline{p}_2(t) - \overline{p}_1(t)$ for each match. Thus, each match corresponds to a line on the figure. A small random error has been added to each line to help indicate the number of matches at each point. The end of a match is indicated by a square. For state 1, convergence is equivalent to the difference going to $+1$ or -1. For states 2 and 3, convergence is equivalent to the difference going to $+1$ and -1 respectively. For state 4, convergence implies that the difference goes to 0. The figures are roughly consistent with convergence.

Experience

The analysis above is at a highly aggregated level. In this section we break down the analysis according to how much experience a subject has had. Recall that in each session, subjects play up to 14 matches, each one of which is an "infinitely" repeated game. Because of the combined presence of asymmetric information and dynamics, one might expect systematic changes in the behavior of subjects across matches, as they become more experienced in the task and become more familiar with the strategic subtleties of the environment. That subjects adjust their behavior in predictable ways has been well-documented in most experimental environments.

We first examine behavior by high-cost types. We find that there is no significant change in behavior for these types (see Table 2) between the first five matches and the remaining matches. While there is 50% more giving-in by inexperienced low types, this is based on very small numbers (a total of 10 observations of giving-in out of 108 chances).

In contrast, the behavior of low-cost types changes a lot with experience. Figure 9 displays the give-in frequencies in the first, second and third moves as a function of experience, conditional on both players in the match having held out in previous moves.

Here we use a finer breakdown of the experience variable. For the first move data, there is sufficient data so that we are able to break it down by the match number. That is, data from "match number 1" pools the data of all low-cost type moves from the first match that has been played during the session.[3] In the data from move 2, there was insufficient data to do this, since cases are excluded if either player gave in on move 1. Therefore, we report 3-match moving averages for the move 2 data. That is, the data reported as match number 2 data in the figure is averaged over matches 1, 2, and 3. In general, the data reported as match number t is averaged over matches t-1, t and t+1. The same is true for the move 3 data.

The results are striking. Experience leads low-cost players to hold out more frequently in the early stages of a match, when neither player has given in yet. This leads to giving-in frequencies more in line with the theoretical predictions. Recall (Table 3) that the prediction is for give-in frequencies below 20% in the early rounds of a match, and that there should be virtually no difference in the give-in probabilities between moves 1, 2, and 3. Inexperienced subjects systematically violate both of these predictions: For example, in match 2, subjects give in 40% of the time in the first move, 55% of the time on the second (conditional) move, and 100% of the time on the third (conditional) move. While the order is consistent with the theory (give-in frequencies should be increasing in the move), both the magnitudes of the give-in frequencies and the magnitude of the cross-move differences in the give-in probabilities are much too large. By the end of a session (match 10), give in probabilities have dropped to around 20% in all three moves, with no significant cross-move differences.

Finally, we examine the effect of experience on the ex post guessing accuracy of the players. Here the theoretical predictions differ depending on the state, and depending on whether the guess is made by a high-cost type or a low-cost type. We break down the data by match number, taking 3-match moving averages as above for states 2 and 3, due to small sample sizes. State 4 (High,High) occurred only ten times, so this was excluded entirely. The results are displayed in Figure 9. In all cases, experience leads to more accurate guessing. Recall that this is different from the result we obtained for "within match" experience. That is, subjects did not guess better in longer matches than they did in shorter matches (Table 7). Thus we conclude that it is experience across matches that matters. The improvement in guessing accuracy is particularly strong for low types in states 2 and 3, where accuracy improves from 42% to 80%.

[3] More precisely, it is the first incomplete information match. Recall that there were four complete information matches that preceded the incomplete information matches.

Pooling across all states and types, overall accuracy begins under 60% and ends up just over 75%. Since the probability of playing a low opponent is 75%, this is almost exactly the accuracy that would occur by making the best guess at the beginning of the game, conditioning only on one's own assigned type (i.e. guess the other player is a low-type). One surprising feature of the experience data is that there is very little difference in the guessing accuracy of experienced high-types and low-types in games 2 and 3. Theoretically there should be a difference, with high-type accuracies near 1 and low-type accuracies between .5 and .75.

Summary

In summary, we see significant deviations from the symmetric belief stationary equilibrium. Most significantly, we find

- The probability of giving in before either subject has revealed is consistently too high, (.45 vs .12) but converges toward the equilibrium with experience.
- The Low types will occasionally (about 10% of the time) give in and reveal themselves to be Low even after their opponent has done so.
- There is no evidence of a mixed equilibrium once both subjects have revealed. Rather, one subject gets stuck giving in for ever.
- The High types, especially on their first move, do not always adopt their dominant strategy of always holding out (10% error rate on the first move.)
- Experience leads to more accurate inferences by subjects about the type of opponents they are facing.

5 CONCLUSIONS

The theoretical model based on the Bayesian equilibrium of an infinitely repeated game generates predictions that are not well-supported in data from inexperienced subjects, but are much better supported in data from experienced subjects. The give-in probabilities of low-cost types are significantly higher than theory would predict, but steadily decline and approach the theoretical predictions as subjects gain experience. The ability of subjects of make accurate inferences about which game they are engaged in (i.e. ability to identify the opponent's type from observed histories) also shows a steady improvement with experience. The two qualitative predictions that seem to hold up regardless of experience are: 1) high types rarely give in (rare violation of dominated strategies); and 2) if a low-type player gives in before its opponent gives in, that player gives in in almost all subsequent moves of the match. The only qualitative prediction that completely fails, with experienced subjects as well as inexperienced subjects, is that we do not observe mixing behavior by low types in matches where both players gave in for the first time on the same move. Rather, following such histories, one of the two players eventually ends up contributing in (almost) all later moves, while the other player (almost) exclusively holds out.

We believe the last observation is due to the fact that in the game of complete information played by two low-cost types (which is simply a version of the game Chicken), the mixed strategy equilibrium is unstable, under many definitions of stability of a Nash equilibrium (e.g. Cournot stability, fictitious play, replicator dynamic, etc.). The only stable equilibria of that game are the two asymmetric pure strategy equilibria in which one player gives in and the other holds out. We conjecture that there is an alternative model, related to stability, that is well-suited to the incomplete information environment in our experiments and that can also explain the fact that the play of these games always eventually comes down to exactly one of the low-types giving in. The model is based on "imperfect play" of the sort studied in McKelvey and Palfrey (1992), El-Gamal and Palfrey (1993), El-Gamal, McKelvey and Palfrey (1993), and Schmidt (1992). These models are similar in spirit to ideas developed by Harsanyi (1973) and Selten (1975), both of which introduce the possibility of "noisy play" in a rigorous (but different) way. Suppose that players cannot perfectly implement a behavioral strategy, but may instead accidentally choose some other (nonequilibrium) behavioral strategy with some probability, and further suppose that these trembling probabilities are commonly known by all the players. This produces a more complicated game of incomplete information in which the inferences by players about their opponent's type can never rule out either type. That is, if a player observes an opponent give in, there is some probability that the opponent is a high-cost type who erred. This means, for example, that even when both players are low types and they both give in first at the same move, the continuation stage game is not the complete information game of chicken, but simply a game of incomplete information in which both players are more likely to be low-cost types than in the previous move. More importantly, if in the continuation game one of the players happens to give in before the other, that player then becomes the more likely one to be a low-cost type. We conjecture that the equilibrium to this error version of the game will have the property that, as the probability of errors becomes small, later moves of a match (with at least one low-cost type) will necessarily see one player giving in with probability close to one and the other player holding out with probability close to one. Moreover, in the equilibrium of this perturbed game, there would always be some small probability (increasing with the probability of error) that two low-cost players will at some point appear to "reverse roles", with the player who had been holding out giving in and the player who had been giving in holding out.

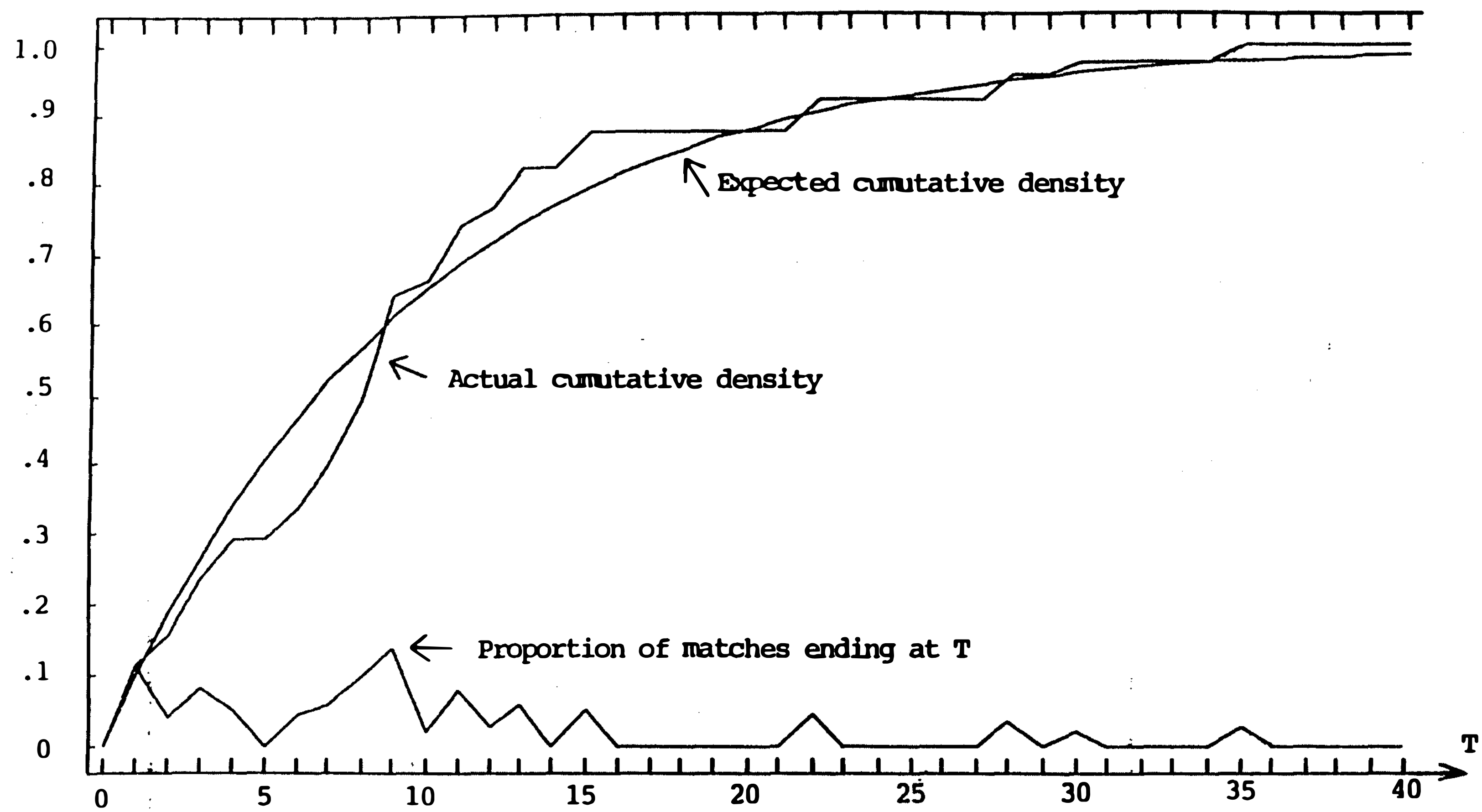


FIGURE 1

Actual and Predicted Frequency Distribution
of Match Lengths

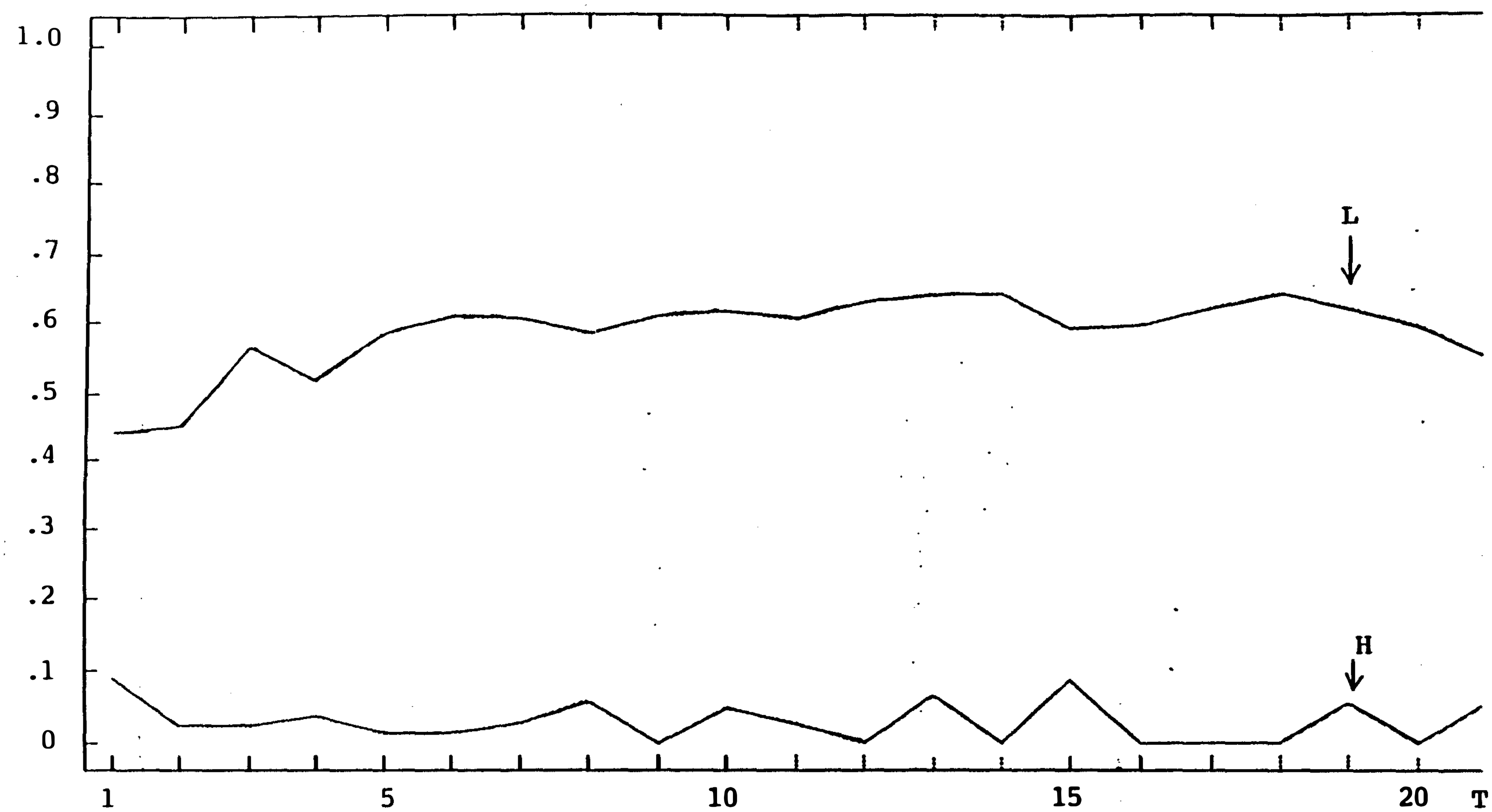


FIGURE 2

Proportion Giving in by type of Subject (H or L) and Round (T)

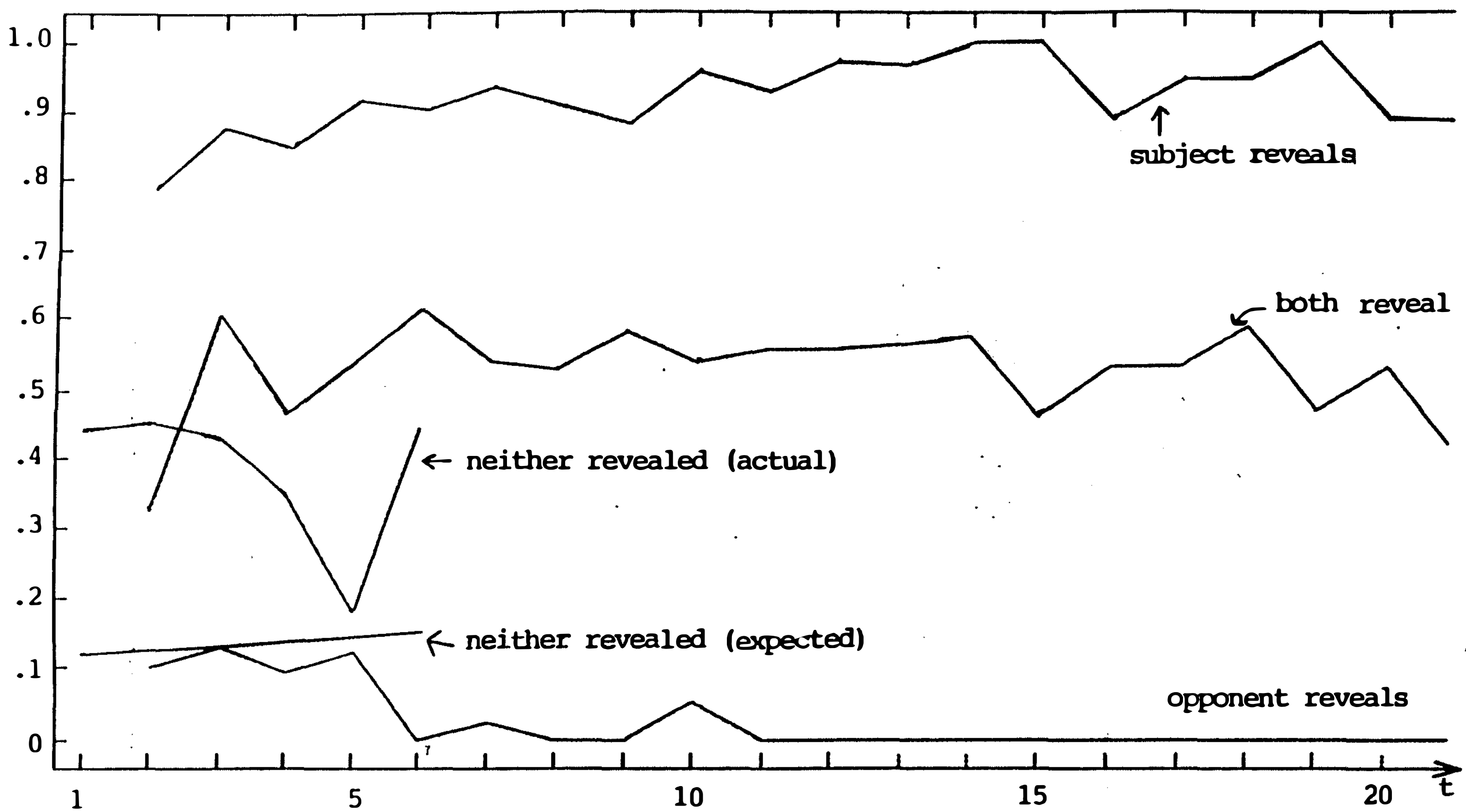


FIGURE 3

Proportion of Low types Giving in by whether Subject and opponent have revealed or not

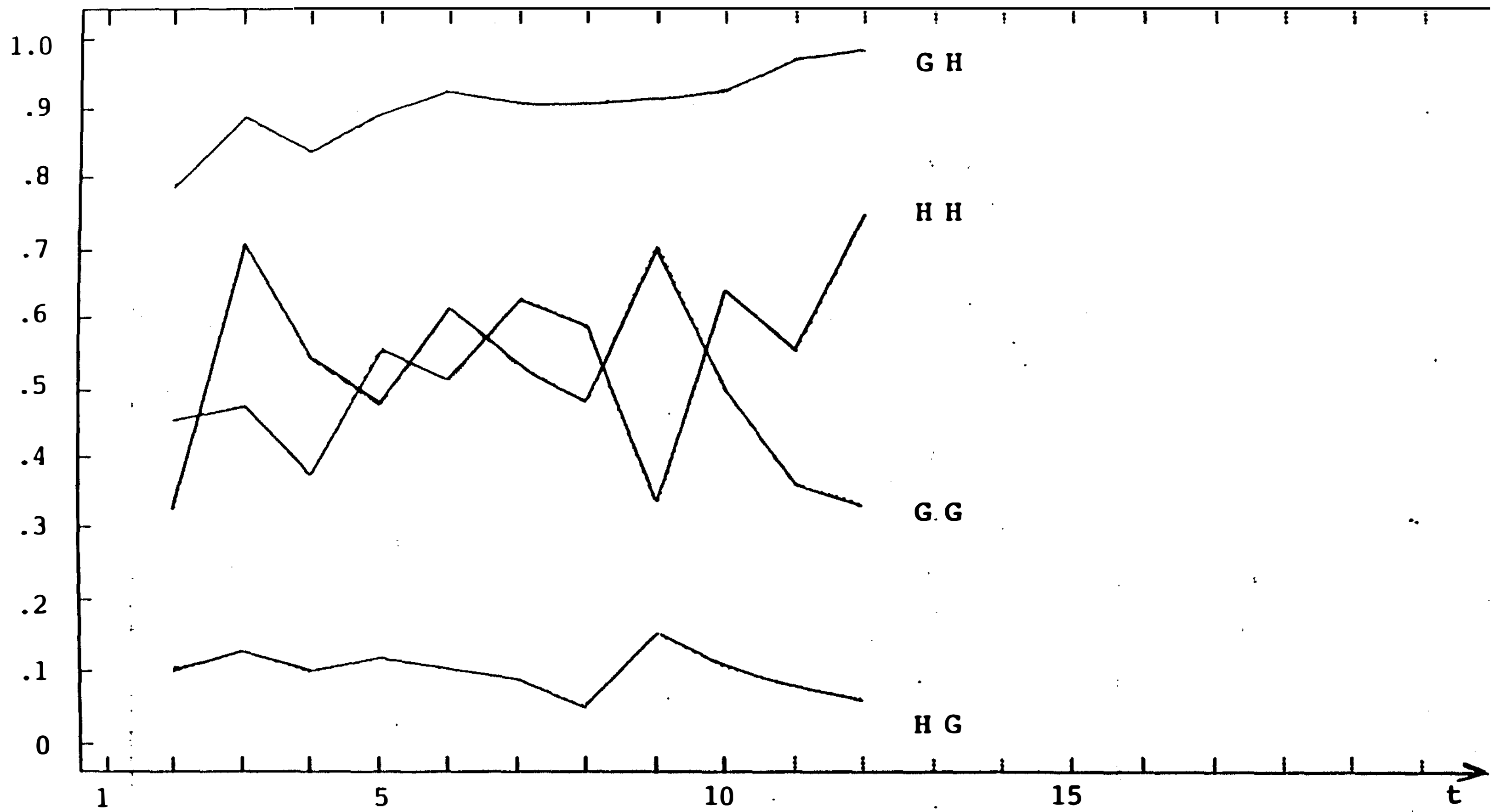


FIGURE 4

Proportion of Low types giving in by actions in previous round

DIFFERENCES IN CUMULATIVE HOLDOUT PROBABILITIES, BY PERIOD
STATE 1, BOTH PLAYERS LOW COST

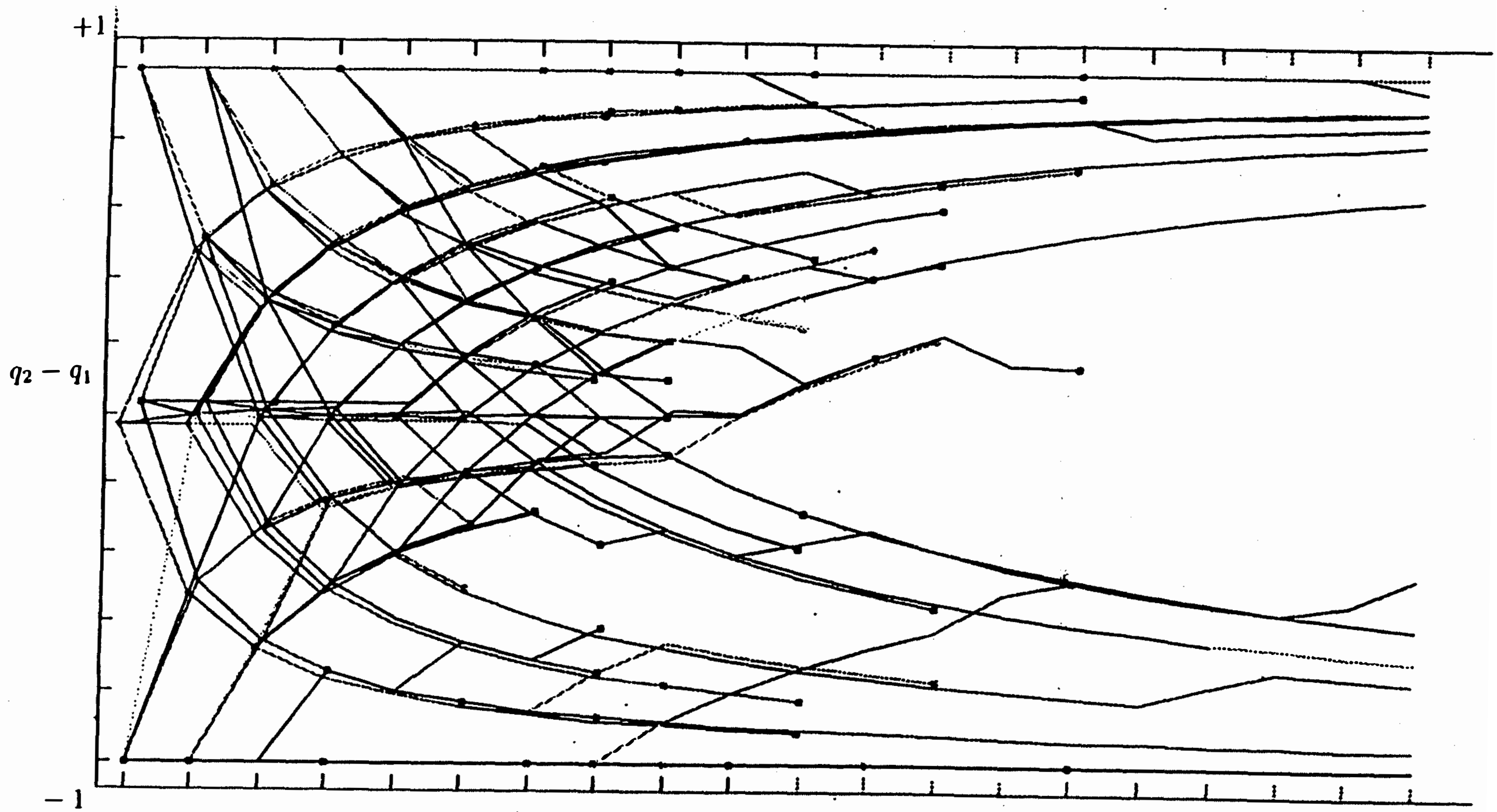


Figure 5

Period (t)

DIFFERENCES IN CUMULATIVE HOLDOUT PROBABILITIES, BY PERIOD
STATE 2, PLAYER 1 LOW COST
PLAYER 2 HIGH COST

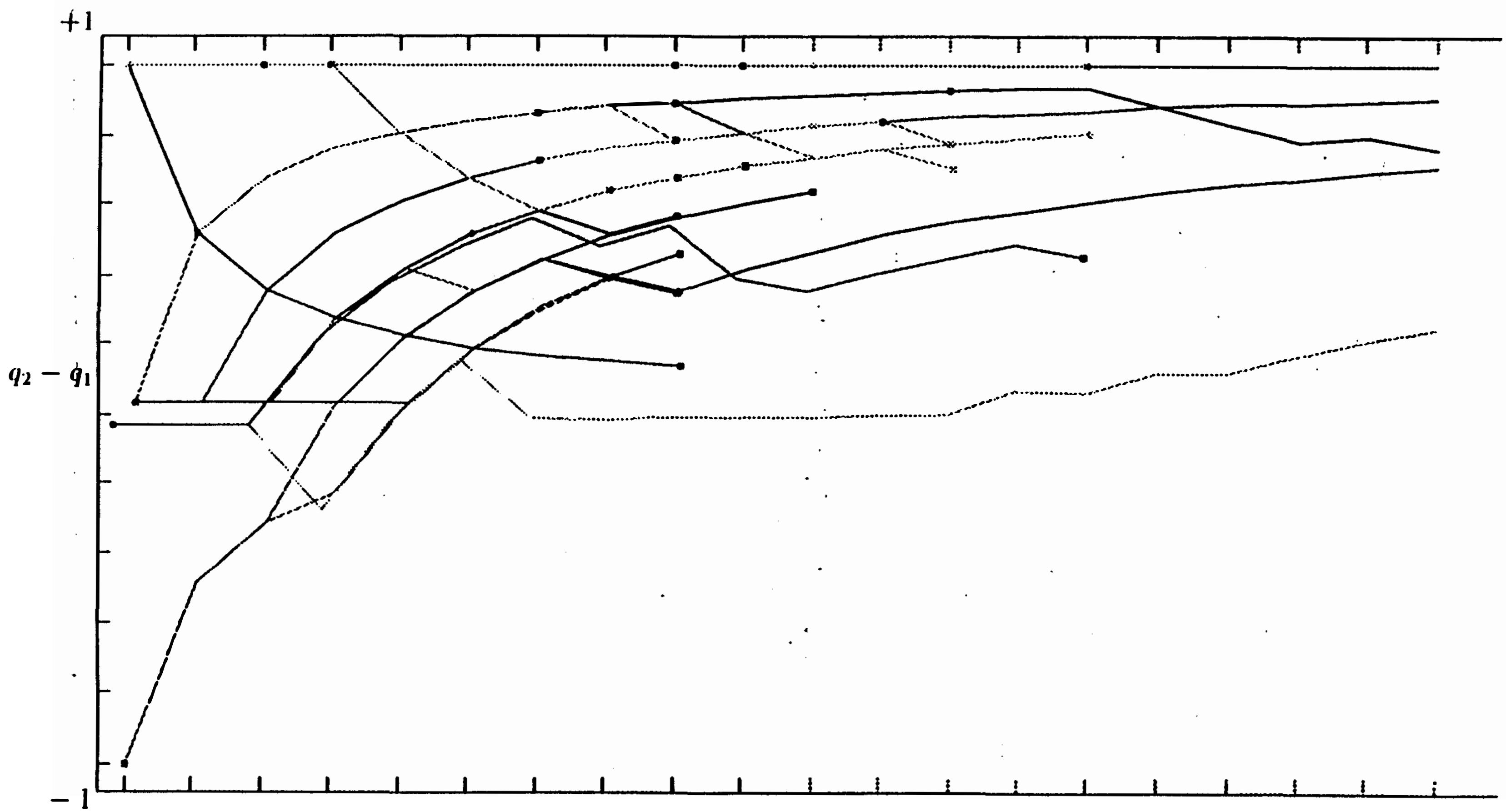


Figure 6

Period (t)

DIFFERENCES IN CUMULATIVE HOLDOUT PROBABILITIES, BY PERIOD
STATE 3, PLAYER 1 HIGH COST
PLAYER 2 LOW COST

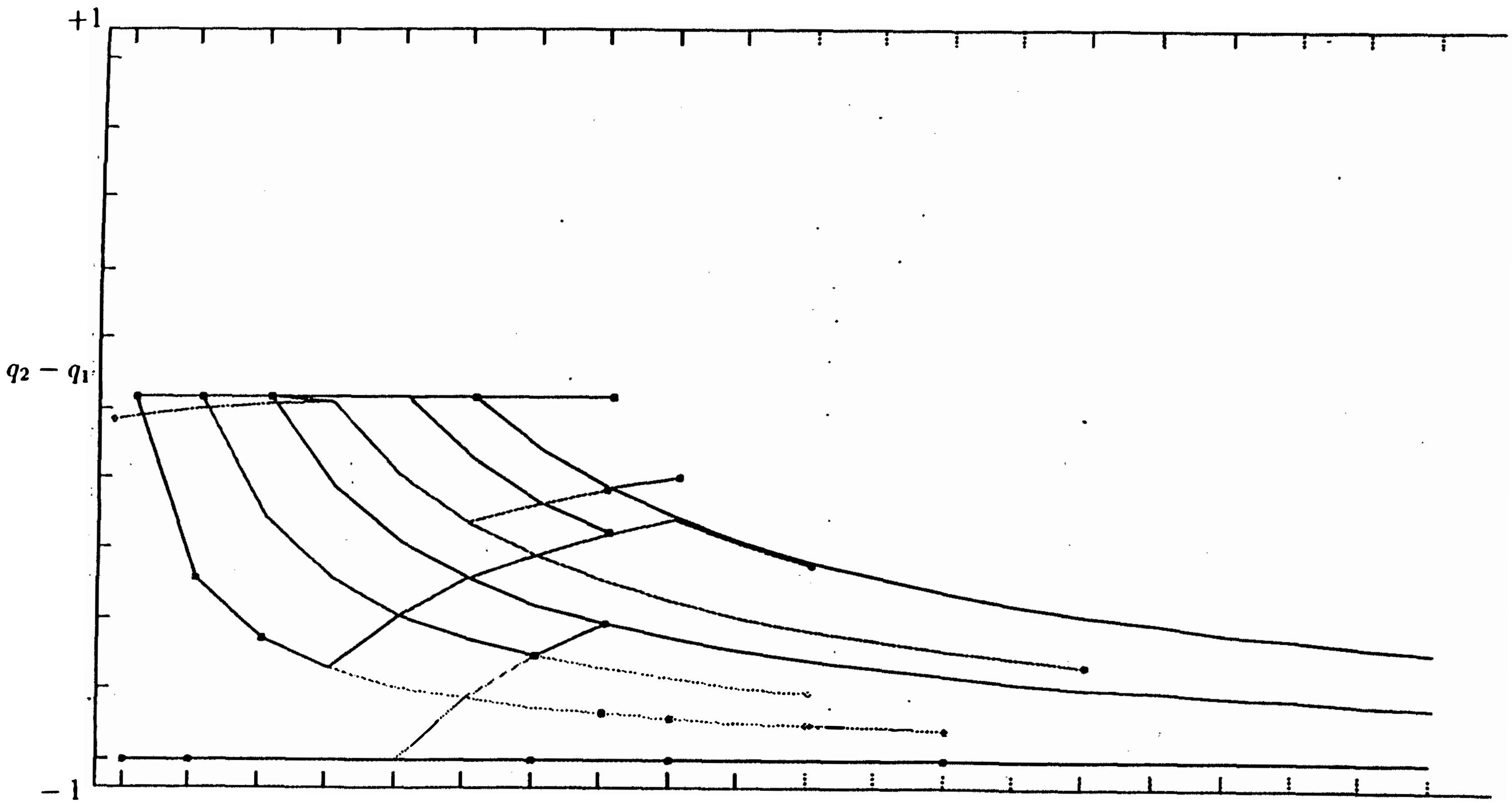


Figure 7

Period (t)

DIFFERENCES IN CUMULATIVE HOLDOUT PROBABILITIES, BY PERIOD
STATE 4, BOTH PLAYERS HIGH COST

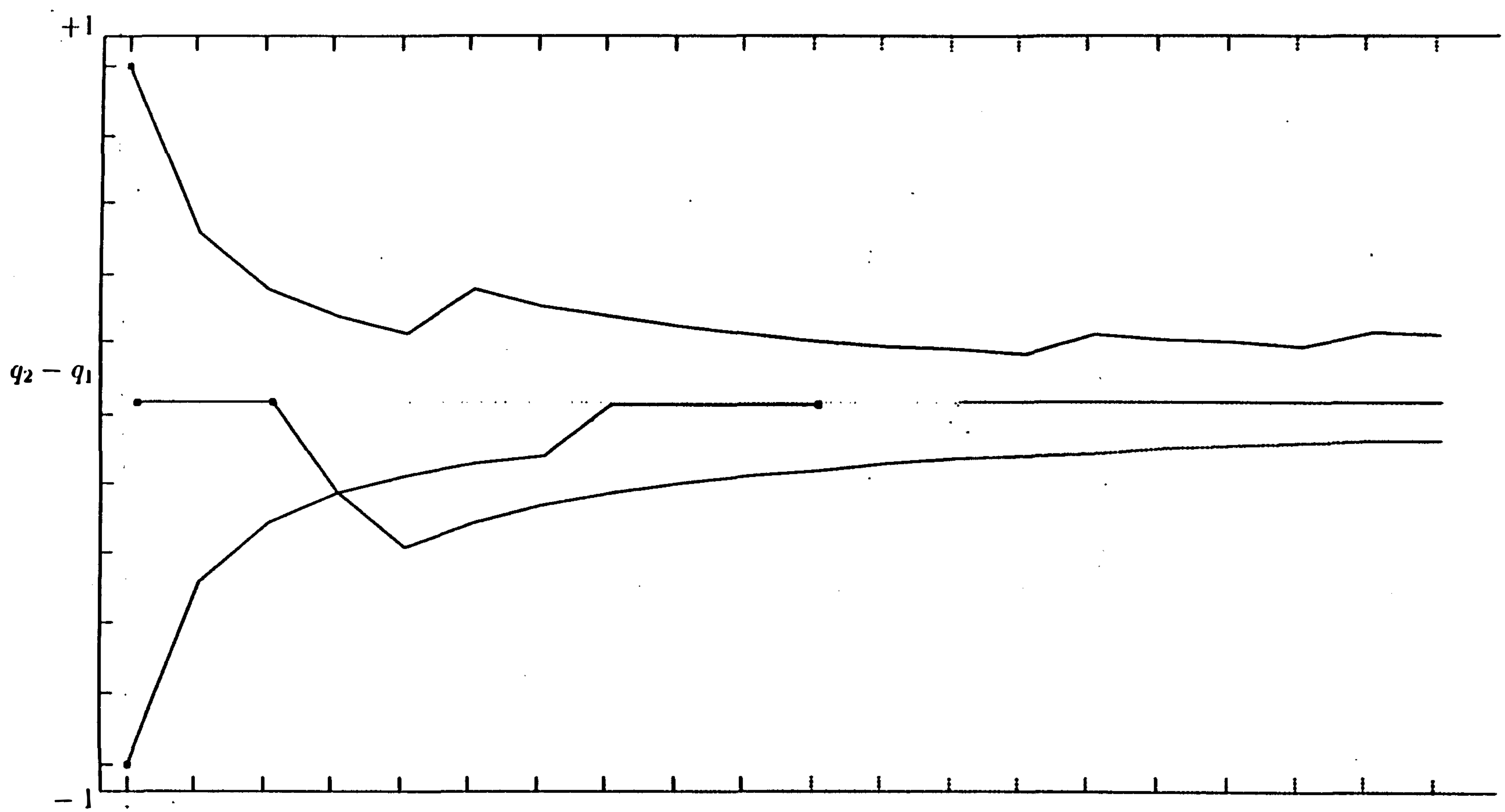
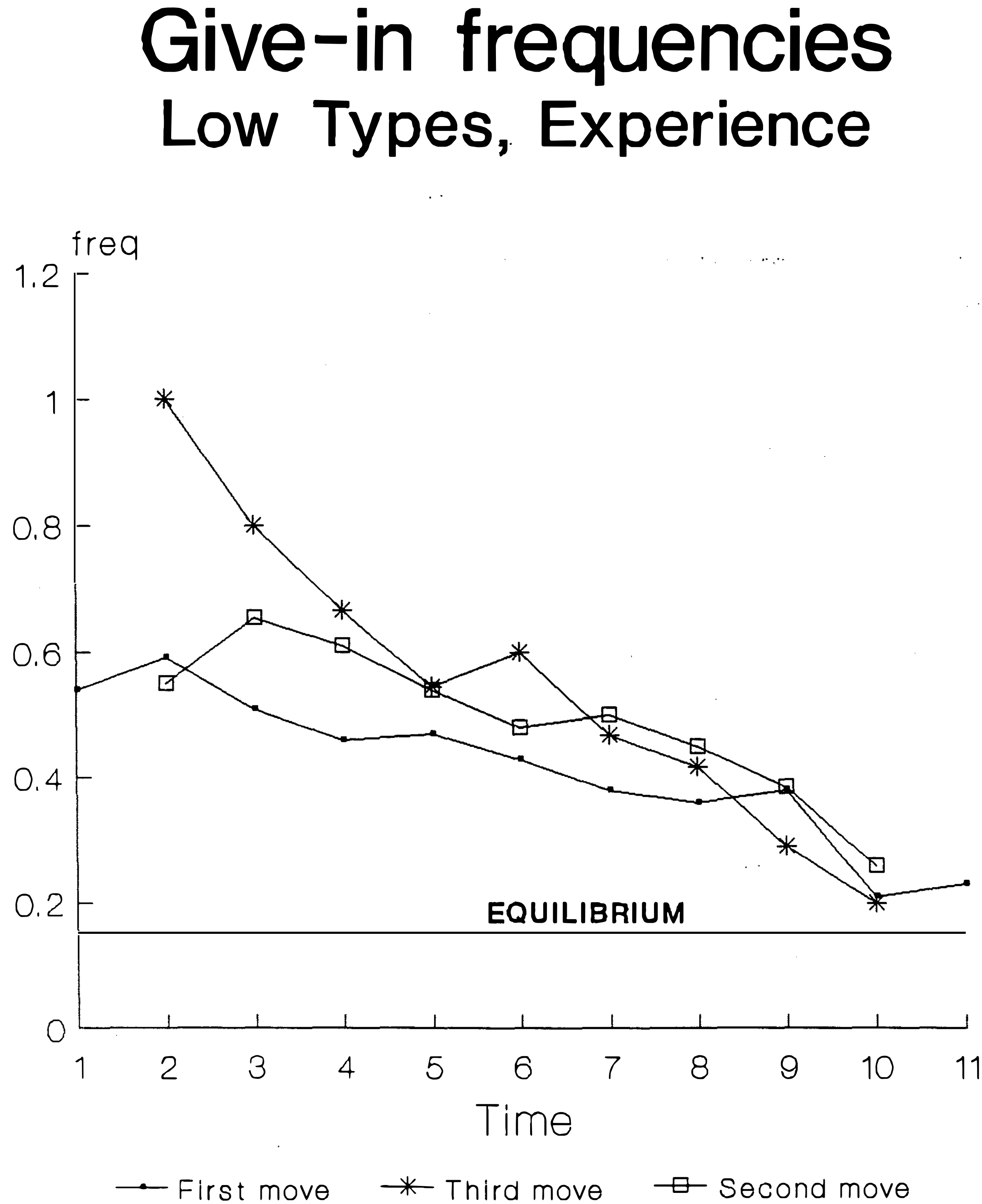


Figure 8

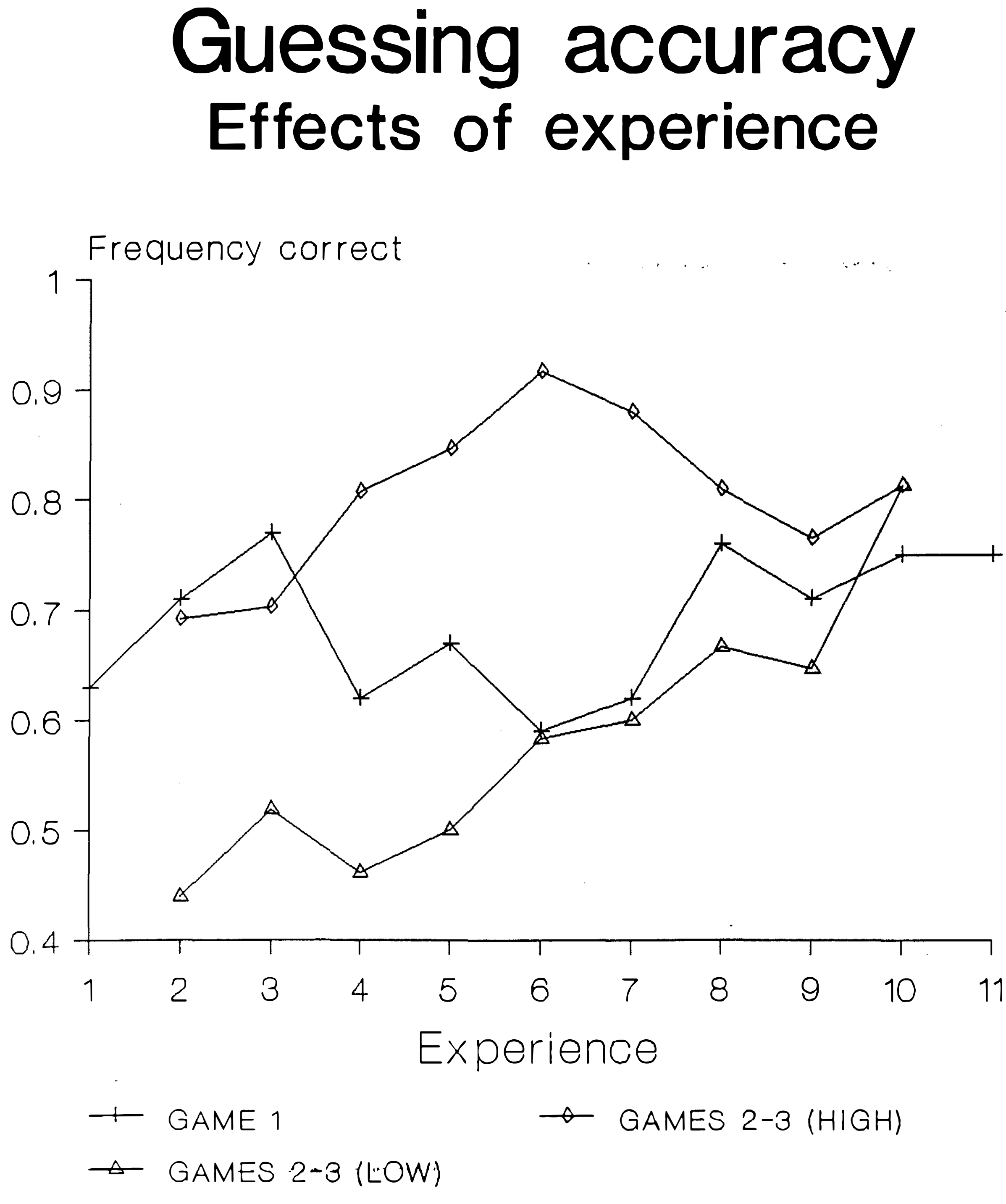
Period (t)

Figure 9



Second and third move data is
3-match moving average.

Figure 10



Game 4 excluded (too little data)
Game 4 overall accuracy = .74
Games 2-3 use 3-match moving average

APPENDIX A

Instructions for the Experiments

This is an experiment in group decision making, and you will be paid for your participation ***in cash***, at the end of the experiment. Different subjects may earn different amounts. What ***you*** earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. It is important that you not talk or in any way try to communicate with other subjects during the experiments. If you disobey the rules, we will have to ask you to leave the experiment.

We will start with a brief instruction period. During the instruction period, you will be given a complete description of the experiment and will be shown how to use the computers. If you have any questions during the instruction period, raise your hand and your question will be answered so everyone can hear.

The subjects will be divided into two groups, containing equal number of subjects. The groups will be labeled the RED group and the BLUE group. To determine which color you are, will you each please select an envelope as the experimenter passes by you.

[EXPERIMENTER PASS OUT ENVELOPES]

If you chose BLUE, you will be BLUE for the entire experiment. If you chose RED, you will be RED for the entire experiment. Please remember your color, because the instructions are slightly different for the BLUE and the RED subjects.

[DISPLAY PAYOFF TABLES USING AN OVERHEAD]

1

	A	B
A	4,4	4,6
B	6,4	2,2

2

	A	B
A	4,1	4,5
B	6,1	2,4

3

	A	B
A	1,4	1,6
B	5,4	4,2

4

	A	B
A	1,1	1,5
B	5,1	4,4

[Note: The row payoffs were written in Red, and the column payoffs were written in Blue. This was also done on the subjects' computer screens.]

The four tables in this figure represent the four possible payoff tables that will be used in this experiment. They are indicated as table 1, table 2, table 3, and table 4.

The experiment will consist of a number of matches. In each match, you will first be matched with another subject of the opposite color. The experimenter will then select one of the four payoff matrices. Whichever one is selected will be the one that you use for the entire match. Each match will consist of a number of rounds. In each round, you and the subject you are matched with will simultaneously choose actions (RED chooses U or D, BLUE chooses L or R). The payoff matrix that is selected gives the payoff, in points, to you and the subject that you are matched with for a single round of the match. You will repeat this for each round.

In each match, after each round, we will roll a four sided die. If it comes up with a 1, then the match will end. Otherwise, we continue with another round. Thus, in each match, we will continue to run additional rounds until the first time the die lands with a 1. For example, if the first time the die comes up with a one is on the third round, then this means that the match will consist of three rounds.

To compute your payoff for a match, we will first compute the match value. This is the value per round times the number of rounds. Each round is worth a value of .15. Thus, the match is worth .15 times the number of rounds in the match. In each match, you will either earn the match value or 0. To determine whether you earn the match value or 0, we compute the number of points you earned in the match and divide it by the maximum possible number of points you could have made. This value is multiplied by 1000 to determine your *score* for the match. (In this case, the maximum possible number of points is 6 times the number of rounds.) Your score represents the number of lottery tickets you own out of a total of 1000. Thus, if your score is 437, you own all the numbers from 0 up to, but not including, 437. To determine your payoff, we will draw a lottery ticket for you between 0 and 999. If the ticket is one of the tickets you own, you win the value of the match. Otherwise, you get nothing for the match.

The experiment consists of several matches. In each match, you are matched with a different player of the opposite color from yours. Thus, if you are a BLUE player, in each game, you will be matched with a RED player. If you are a RED player, in each game you are matched with a BLUE player.

[BEGIN COMPUTER INSTRUCTION]

We will now begin the computer instruction session. During the instruction session, we will teach you how to use the computer by going through a few practice games. During the instruction session, ***do not hit any keys until you are told to do so***, and when you are told to enter information, ***type exactly what you are told to type.*** You are not paid for these practice games.

Please turn on your computer now by pushing the button labeled "MASTER" on the right hand side of the panel underneath the screen.

[WAIT FOR SUBJECTS TO TURN ON COMPUTERS]

When the computer prompts you for your name, type your full name. Then hit the ENTER key.

[WAIT FOR SUBJECTS TO ENTER NAMES]

When you are asked to enter your color, type R if your color is RED, and B if your color is BLUE. Then hit ENTER.

[WAIT FOR SUBJECTS TO ENTER COLORS]

You now see the experiment screen. Throughout the experiment, the bottom of the screen will tell you what is currently happening, and the top will show you the payoff table.

The top line of the upper part of the screen tells you your subject number and your color. Please record your color and subject number on the top left hand corner of your record sheet.

Each of the four possible payoff tables is shown on the upper screen. In this match, the first table has been selected. This is indicated by the fact that the first payoff table is highlighted in gray. This means table one will be used for the entire first match.

The bottom part of the screen prompts you for your input and records the moves that have been made by you and the other subject. The subject that you are matched with is indicated on the second row of the bottom screen. It is important to note that you will be matched with a new subject for each match.

We will now start the first practice game. Remember, do not hit any keys until you are told to do so. If you are a RED subject, you are prompted to enter a choice of the row (U or D). If you are a BLUE subject, you are prompted to enter a choice of a column (L or R). Will all the RED subject please choose U and all the BLUE subjects please choose L on your terminals now. After you enter your choice, you must confirm it by pressing Y.

[WAIT FOR SUBJECTS TO CHOOSE]

Since RED chose U and BLUE chose L, this means that the outcome is in the upper left hand cell of the highlighted table, so that the BLUE subject gets a payoff of XXX, and the RED subject gets a payoff of XXX. The move that was chosen by each subject, as well as your payoff is recorded on the bottom of the screen.

In the actual experiment, at this point, we would throw a four sided die to determine whether to stop the match or continue with another round. For the practice session, we will not actually throw the die, but we will show you what your payoff would be if we threw the first one on the fourth round.

The match now proceeds to the second round. The second round is just like the first. This time, will the RED subject please choose U, and the BLUE subject choose R, and then confirm your choice.

[WAIT FOR SUBJECTS TO CHOOSE]

Since RED chose U and BLUE chose R, this means that the outcome is in the upper right hand cell, so that the RED subject gets a payoff of XXX, and the BLUE subject gets a payoff of XXX. The move that was chosen by each subject, as well as your payoff is again recorded on the bottom of the screen. The match now proceeds to the third round.

[HAVE SUBJECTS DO 2 MORE ROUNDS (DL and DR)]

In the practice match, we are assuming that the match ends after the fourth round. This means that you will be paid for 4 rounds in this match. Enter this number in column (1) of your record sheet. Each round is worth \$.15. So the total value of this match is $V = \$.60$. Enter this in column (2). The total number of points you could have earned is 4 times 6, or 24. Enter this in column (3). Now, add up your own payoffs for the first 3 rounds, and enter this in column (4). Divide this number by 24, and multiply by 1000 to get your score. Enter this number in column (5). Your score is the number of lottery tickets you have earned. You have all of the lottery tickets numbered from 0 up to (but not including) s. To determine your lottery number, we will throw three ten sided dice to determine a number between 0 and 999. You will then add 100 times your player number to this number to determine your lottery ticket. If your lottery ticket is a number below s, then you earn V. If it is above or equal to s, you earn $0.00 for this match.

[THROW DICE to get L]

We have thrown a number L. Enter this number in column (6). If L is below s (your entry in column 6), then enter V into the final column (column 7). If L is above or equal to s, then enter $0.00 into the final column. You are not being paid for the practice session, but if this were the real experiment, then the payoff you have recorded in the column P would be money you have earned from the first match, and you would be paid this amount for that game at the end of the experiment. The total you earn over all of the matches is what you will be paid for your participation in the experiment.

[WAIT FOR SUBJECTS TO RECORD PAYOFFS]

This concludes the practice session. In the actual experiment there will be several matches, and, of course, it will be up to you to make your own decisions. After the last match, the experiment ends and we will pay each of you privately, in cash, the TOTAL amount you have accumulated during all ten games, plus your guaranteed five dollar participation fee. No other person will be told how much cash you earned in the experiment. You need not tell any other participants how much you earned.

Are there any questions before we begin?

[ANSWER QUESTIONS]

We will now begin with the actual experiment. If there are any problems from this point on, raise your hand and an experimenter will come and assist you.

[START EXPERIMENT]

[SECOND PART OF EXPERIMENT]

At this point, we are going to change the rules. You will now be using the same payoff tables as before, and will be paid in exactly the same manner. The only difference will be the information that you have. As before, prior to a match, we will draw one of the four payoff tables to be the one that you will use. However, this time, you will not be told which payoff table is being used. If you are a Red player, you will only be told whether the payoff table is one of the top two or one of the bottom two. If you are the Blue player you will only be told that it is one of the two on the left or one of the two on the right. The information will be indicated on your screen by highlighting one of the possible payoff matrices. You will only know that the correct payoff matrix is one of the highlighted ones. [Note: In the original script, "Blue" and "Red" were reversed in the above paragraph. However, we believe there was no confusion because the information conditions were illustrated using color-coded overhead, where the experimenter explicitly showed which payoff tables would be highlighted for each color of player and the computer screens were color-coded.

We will determine which payoff table to use by rolling two four sided dice. We will roll the first four sided die. If it comes up with a one, we will choose one of the bottom two tables, otherwise we choose one of the top two. We then roll a second four sided die. If it comes up with a one, we choose the right hand table. Otherwise, we choose the left hand table.

DECISION MAKING EXPERIMENT
Record Sheet

Your Color:_____ Your Subject #_____

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	# of rounds	Match Value	Possible Total	Your Total	Your Score	Lottery number	Your Payoff
	n	$V = n \times v$	$T = n \times m$	t	$s = 1000 \times \frac{t}{T}$	L	V if $L < s$ 0 if $L \geq s$
Practice	____	____	____	____	____	____	$ ________
( )( ) 1	____	____	____	____	____	____	$ ________
( )( ) 2	____	____	____	____	____	____	$ ________
( )( ) 3	____	____	____	____	____	____	$ ________
( )( ) 4	____	____	____	____	____	____	$ ________
( )( ) 5	____	____	____	____	____	____	$ ________
( )( ) 6	____	____	____	____	____	____	$ ________
( )( ) 7	____	____	____	____	____	____	$ ________
( )( ) 8	____	____	____	____	____	____	$ ________
( )( ) 9	____	____	____	____	____	____	$ ________
( )( ) 10	____	____	____	____	____	____	$ ________
( )( ) 11	____	____	____	____	____	____	$ ________
( )( ) 12	____	____	____	____	____	____	$ ________
( )( ) 13	____	____	____	____	____	____	$ ________
( )( ) 14	____	____	____	____	____	____	$ ________
( )( ) 15	____	____	____	____	____	____	$ ________
					Participation Fee		$ ________
					TOTAL		$ ________

DATE______________ EXPERIMENT #______________

YOUR NAME (Print)______________________________ SOC SEC # ____________

SIGNATURE______________________________ RECEIVED$ ____________

APPENDIX B

Data, Tables and Figures

The data is in the following format:

Experiment #: 1-4
Match number: 1-∞ (Match 1 was a practice match, matches 2-5 were full information)
Subject color: 1=Red, 2=Blue (only Red data included-Blue can be inferred from Red)
Red subject #: 1-10
Blue subject #: 1-10 (subject number of opponent)
State: 1-4 (1=LL, 2=LH, 3=HL, 4=HH)
Guess: 1-4
Subject Type: 0=Low, 1=High
Number of rounds: 1-∞

The remaining data for each record consists of pairs (r^t, b^t), where r^t is Red's move in round t, and b^t is Blue's move in Round t.

1	1 1 1 1	1 0 0	4	0 0 0 1 1 0 1 1
1	1 1 2 2	1 0 0	4	0 0 0 1 1 0 1 1
1	1 1 3 3	1 0 0	4	0 0 0 1 1 0 1 1
1	1 1 4 4	1 0 0	4	0 0 0 1 1 0 1 1
1	1 1 5 5	1 0 0	4	0 0 0 1 1 0 1 1
1	2 1 1 2	1 0 0	3	1 0 0 0 1 0
1	2 1 2 3	1 0 0	3	1 0 0 0 1 0
1	2 1 3 4	1 0 0	3	0 0 0 1 1 1
1	2 1 4 5	1 0 0	3	1 1 0 0 1 1
1	2 1 5 1	1 0 0	3	0 0 1 0 1 0
1	3 1 1 3	2 0 0	1	0 1
1	3 1 2 4	2 0 0	1	0 1
1	3 1 3 5	2 0 0	1	0 0
1	3 1 4 1	2 0 0	1	0 1
1	3 1 5 2	2 0 0	1	0 1
1	4 1 1 4	3 0 1	1	1 0
1	4 1 2 5	3 0 1	1	1 0
1	4 1 3 1	3 0 1	1	1 0
1	4 1 4 2	3 0 1	1	1 0
1	4 1 5 3	3 0 1	1	1 0
1	5 1 1 5	4 0 1	2	1 1 1 1
1	5 1 2 1	4 0 1	2	1 1 1 1
1	5 1 3 2	4 0 1	2	1 1 1 1
1	5 1 4 3	4 0 1	2	1 1 1 1
1	5 1 5 4	4 0 1	2	1 1 1 1
1	6 1 1 1	2 2 0	9	1 1 0 1 1 1 1 1 0 1 1 1 0 1 1 1 1 1
1	6 1 2 2	4 4 1	9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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4	1 1 5 5	1 0 0	4	0 0 0 1 1 0 1 1
4	1 1 6 6	1 0 0	4	0 0 0 1 1 0 1 1
4	2 1 1 2	2 0 0	1	1 1
4	2 1 2 3	2 0 0	1	0 1
4	2 1 3 4	2 0 0	1	1 1
4	2 1 4 5	2 0 0	1	0 1
4	2 1 5 6	2 0 0	1	1 1
4	2 1 6 1	2 0 0	1	1 1
4	3 1 1 3	3 0 1	1	1 1
4	3 1 2 4	3 0 1	1	1 0
4	3 1 3 5	3 0 1	1	1 0
4	3 1 4 6	3 0 1	1	1 0
4	3 1 5 1	3 0 1	1	1 1
4	3 1 6 2	3 0 1	1	1 1
4	4 1 1 4	4 0 1	1	1 1
4	4 1 2 5	4 0 1	1	1 1
4	4 1 3 6	4 0 1	1	0 1
4	4 1 4 1	4 0 1	1	1 1
4	4 1 5 2	4 0 1	1	1 1
4	4 1 6 3	4 0 1	1	1 1
4	5 1 1 5	1 0 0	23	0 1 1 0 1 1 0 1 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1
				0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 1
4	5 1 2 6	1 0 0	23	1 0 1 0 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
				1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
4	5 1 3 1	1 0 0	23	0 1 0 0 0 1 0 1 1 1 0 0 0 1 1 0 1 1 0 1 1 0 0 0 0 1 0 0 1 1

				1 1 1 0 1 0 0 0 1 0 1 1 1 1 1 1
4	5 1 4 2	1 0 0	23	1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 0 1 1 0
				1 1 1 1 0 0 0 0 1 1 0 1 1 0 1 1
4	5 1 5 3	1 0 0	23	1 1 1 0 1 0 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
				1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
4	5 1 6 4	1 0 0	23	0 0 0 0 0 1 1 1 0 1 0 1 0 1 0 1 1 1 1 1 0 1 0 1 0 1 0 1 1 1
				1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
4	6 1 1 6	1 0 0	6	1 0 1 0 0 0 0 1 1 1 0 0
4	6 1 2 1	1 0 0	6	0 0 0 1 1 1 0 1 0 0 0 1
4	6 1 3 2	1 0 0	6	1 0 1 0 1 1 0 1 1 0 1 0
4	6 1 4 3	1 0 0	6	0 1 0 1 0 1 1 1 0 0 1 0
4	6 1 5 4	1 0 0	6	1 1 1 1 0 0 0 0 0 0 0 0
4	6 1 6 5	1 0 0	6	0 1 0 1 1 0 1 0 1 0 1 1
4	7 1 1 1	2 2 0	7	0 1 0 1 0 1 0 1 1 1 0 1 0 1
4	7 1 2 2	1 2 0	7	1 1 1 0 1 0 1 1 0 0 1 1 1 1
4	7 1 3 3	1 1 0	7	0 1 0 1 0 1 0 1 0 0 1 0 1 0
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4	7 1 5 5	1 1 0	7	1 0 1 1 1 1 0 1 0 1 0 0 0 0
4	7 1 6 6	2 1 0	7	1 1 1 1 0 1 0 1 0 1 0 1 0 1
4	8 1 1 2	1 1 0	12	0 1 0 0 0 1 0 0 0 1 1 1 0 0 1 1 0 1 0 0 0 1 0 0
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4	8 1 6 1	2 1 0	12	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 1 1 0 1 0 1
4	9 1 1 3	1 1 0	11	0 0 1 1 0 0 0 1 0 1 1 1 0 0 0 0 0 0 0 1 0 0
4	9 1 2 4	1 2 0	11	0 1 1 1 0 1 1 1 0 1 0 1 0 1 1 1 1 1 1 1 1 1
4	9 1 3 5	3 4 1	11	1 1 1 1 1 0 1 0 1 0 1 1 0 0 1 1 1 1 1 0 1 0
4	9 1 4 6	1 1 0	11	0 0 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
4	9 1 5 1	1 2 0	11	1 1 0 0 0 0 1 1 0 1 0 0 0 0 0 1 0 0 0 1 0 1
4	9 1 6 2	1 1 0	11	1 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1 0 1 1 1 0 0
4	10 1 1 1	2 2 0	9	1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1
4	10 1 2 2	1 1 0	9	0 0 0 1 1 0 0 1 0 0 1 1 1 0 1 1 0 0
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4	10 1 4 4	3 3 1	9	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
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4	10 1 6 6	1 1 0	9	1 0 0 0 0 1 1 1 0 0 0 0 0 1 0 1 1 1
4	11 1 1 2	1 1 0	1	0 0
4	11 1 2 3	1 1 0	1	1 0
4	11 1 3 4	3 3 1	1	1 0
4	11 1 4 5	2 2 0	1	0 1
4	11 1 5 6	4 4 1	1	0 1
4	11 1 6 1	1 1 0	1	1 1
4	12 1 1 3	2 2 0	9	0 1 1 1 1 1 0 1 0 1 0 1 1 1 1 1 0 1
4	12 1 2 4	1 1 0	9	1 0 1 1 1 0 0 0 1 0 1 0 1 0 1 0 1 0
4	12 1 3 5	1 1 0	9	1 1 1 1 0 0 0 0 1 1 0 1 0 0 0 0 0 1
4	12 1 4 6	1 2 0	9	1 1 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1
4	12 1 5 1	1 1 0	9	0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
4	12 1 6 2	1 2 0	9	1 1 0 0 0 1 0 0 1 1 1 0 1 1 1 0 0 0
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4	13 1 2 5	1 1 0	15	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
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4	13	1 4 1	1 2 0	15	0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
4	13	1 5 2	1 1 0	15	0 0 0 1 0 0 0 1 0 0 0 1 0 1 0 1 0 1 0 0 0 1 0 1 0 1 0 1 0 1
4	13	1 6 3	2 1 0	15	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 1 1 0 1 0 1 0 1 0 0 0 1 0 1
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4	14	1 2 6	1 1 0	15	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
4	14	1 3 1	3 3 1	15	1 1 1 1 1 1 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
4	14	1 4 2	2 2 0	15	0 1 0 1 0 1 0 1 1 1 1 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
4	14	1 5 3	2 1 0	15	0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 0 1 1 0 0 0 0 1 0 1 0 1 0 0
4	14	1 6 4	1 2 0	15	1 1 1 0 1 0 1 1 1 1 1 1 0 1 1 1 0 1 0 0 0 1 0 1 0 1 1 0 1 1

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